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Technological Advances in Radiological Contingency Planning for the 2011 Mars Science Laboratory Mission

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Abstract. The KSC Radiological Contingency Plan (RCP) (Cabana, 2011) serves to prepare response agencies for the unlikely event of an accidental atmospheric release of radiological material from a launch anomaly involving a Radioisotope Power System (RPS). In this paper we discuss three areas of new technological improvements in the RCP for the 2011 Mars Science Laboratory (MSL) mission, which carried a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG). First, to enhance coordination of local, state, and federal assets, NASA completely redesigned KSC's Radiological Control Center (RADCC). Second, to improve the ability to detect a potential release and make timely emergency response decisions, NASA deployed a network of automated radiological air samplers to supplement the traditional field team sampling. A network of 30 Environmental Continuous Air Monitors (ECAMs) provided near real-time radiological air concentrations to the RADCC as well as to DOE's National Atmospheric Release Advisory Center (NARAC) at LLNL. The third area of new technology involved sharing of information via several controlled Web sites. Sharing information via the Web facilitated a Common Operational Picture between response agencies and helped public affairs specialists in the Joint Information Center (JIC) to prepare timely announcements of possible protective actions at various public launch viewing venues at the launch site and in the local community. A successful launch occurred at 10:02 am EST on November 26, 2011. About 45 minutes later, after MSL was successfully injected on its trajectory toward Mars, the extensive interagency resources of the RCP stood down. We expect that the advances developed for MSL will be applied to future RPS-powered NASA missions which have yet to be selected.

Keywords: Radiological Contingency Planning, Mars Science Laboratory, Multi-Mission Radioisotope Thermoelectric Generator.

INTRODUCTION

Low probability events with high potential consequences demand preparation commensurate with the potential consequences. The probability of a radiological release in the launch area due to an accident involving the MSL MMRTG was estimated at 0.2% (1 in 420) (NASA, 2006). A launch anomaly involving vehicle destruction within the first 50 s could result in a fall of debris over land potentially followed by a solid propellant fuel fire involving the MMRTG. This scenario was estimated to result in a mean release of 12 Ci of ^{238}Pu and a mean individual dose of 0.1 rem (NASA, 2006). To prepare for such a low probability high risk event, NASA led the development of a detailed RCP with expert assistance from the following organizations:

- Federal: NASA, DOE, FEMA, U.S. Air Force (USAF), and U.S. Environmental Protection Agency (USEPA)
- NASA contractor: Jet Propulsion Laboratory (JPL)
- DOE contractors: Lawrence Livermore National Laboratory (LLNL), Remote Sensing Laboratory (RSL), and Oak Ridge National Laboratory Radiation Emergency Assistance Center/Training Site (REAC/TS)
- State of Florida: Department of Emergency Management (FLDEM) and Bureau of Radiation Control (FLBRC)

- Brevard County: Department of Emergency Management (BCDEM)

The MSL RCP covers emergency response actions both onsite at KSC as well as initial recommendations for an offsite response. The interagency developed the RCP based on the fundamental principles of advanced preparation including:

- Detailed coordinated procedures and checklists
- Rehearsals of simulated launch-accident responses
- Timely availability of technically accurate and reliable information
- Prompt external communication with the media and general public, including the active use of social media

The primary goals of RCP included:

- To assess whether a release of radioactive material has occurred due to a launch-area accident
- To quantify the magnitude and nature of any material released
- To predict where the material is likely to be dispersed (if at all)
- To formulate guidance on any appropriate protective actions to be taken

Significant new technology improvements greatly enhanced RCP capability for MSL over previous missions. This paper describes the advancements in the following areas:

1. A redesigned Radiological Control Center
2. New automated radiological monitoring
3. New Web-based tools that enhanced situational awareness, interagency coordination, and public communications

THE REDESIGNED RADIOLOGICAL CONTROL CENTER (RADCC)

The RADCC is the primary facility at KSC for the coordination of all radiological contingency planning and initial response activities. Following the launch of the Pluto New Horizons mission in January 2006, planners recognized that a modernization of the RADCC would improve the overall efficiency of any response activity. To enhance close communication, the data collection and assessment were consolidated with the management decision-making functions of the radiological contingency response. Between 2006 and 2009, the RADCC received extensive upgrades of communication and computing systems and expansion to accommodate RCP team members in a single facility. A touch-screen video display system was installed to facilitate command and control. Nine high-definition monitors and four projector screen displays could be switched to display RADCC computers or console laptops, NASA and KSC video feeds, or cable news channels. Displays included location of field deployed assets, plume plots, RADCC operational checklists, launch support, real-time video of the launch pad, and if an accident occurred, that status. Figures 1 and 2 show the two main RADCC rooms – a technical support area and the Coordinating Agency Representative (CAR) Management Group (CMG). The redesigned RADCC facilitated a more efficient and coordinated approach to data collection and assessment, and delivery of the most up-to-date information in the event of an accident.

In the technical support area, NASA's RADCC Technical Director led 25 staff who performed the five following functions:

1. Collection of field measurement data via deployed personnel field teams and automated monitoring stations
2. Data assessment, first to determine whether a release of radioactive material had occurred and second to make an initial estimate of the quantity of material released
3. Formulation of recommendations regarding protective actions that could be taken in onsite or offsite locations and communicating those recommendations to the CMG
4. Coordination with onsite and offsite response organizations and agencies to communicate information related to the data assessment activity, and protective action recommendations, and provide ongoing status of radiological response
5. Delivery of information to the Joint Information Center (JIC) to assist in formulation of public information releases.

FIGURE 1. New RADCC technical support area.

FIGURE 2. The RADCC CAR Management Group (CMG).

NASA's federal Coordinating Agency Representative (CAR) led the CMG, which consisted of representatives from NASA, JPL, USAF, DOE, FLDEM, BCDEM, FEMA, and the USEPA. The CMG was responsible for making decisions governing the overall radiological response. The CMG was also the senior management coordination point regarding the ongoing status of radiological response, and approval of public affairs messages via coordination with the JIC.

Located a few doors from the RADCC, the JIC included public affairs specialists from NASA, JPL, DOE, USAF, KSC, EPA, FEMA, FLDEM, and BCDEM (Figure 3). The RADCC provided the JIC with regular updates on potential accident conditions. The JIC also had liaison positions in both the RADCC technical support area and the CMG. The JIC was responsible for communicating information concerning any protective-action recommendations (PARs) deemed prudent by the RADCC Assessment Team and approved by the CAR for the surrounding communities. The JIC was prepared to distribute messages to the NASA launch commentator, the NASA KSC news center, and the state and local emergency operations teams. In addition to using standard media channels, JIC specialists would have made relevant messages available to the public via the Web, text messaging, and social media feeds, which were widely advertised before launch.

FIGURE 3. Joint Information Center (JIC).

Figure 4 shows the agency and team coordination which included a total of 41 local, state, federal, and contractor organizations (Brisbin and Scott, 2011). The RADCC was in direct contact with both the Brevard County and the Florida emergency operations centers. NASA Headquarters and Department of Homeland Security (DHS) operations centers in Washington, DC were also included in case the response required federal coordination according to the National Response Framework (NRF).

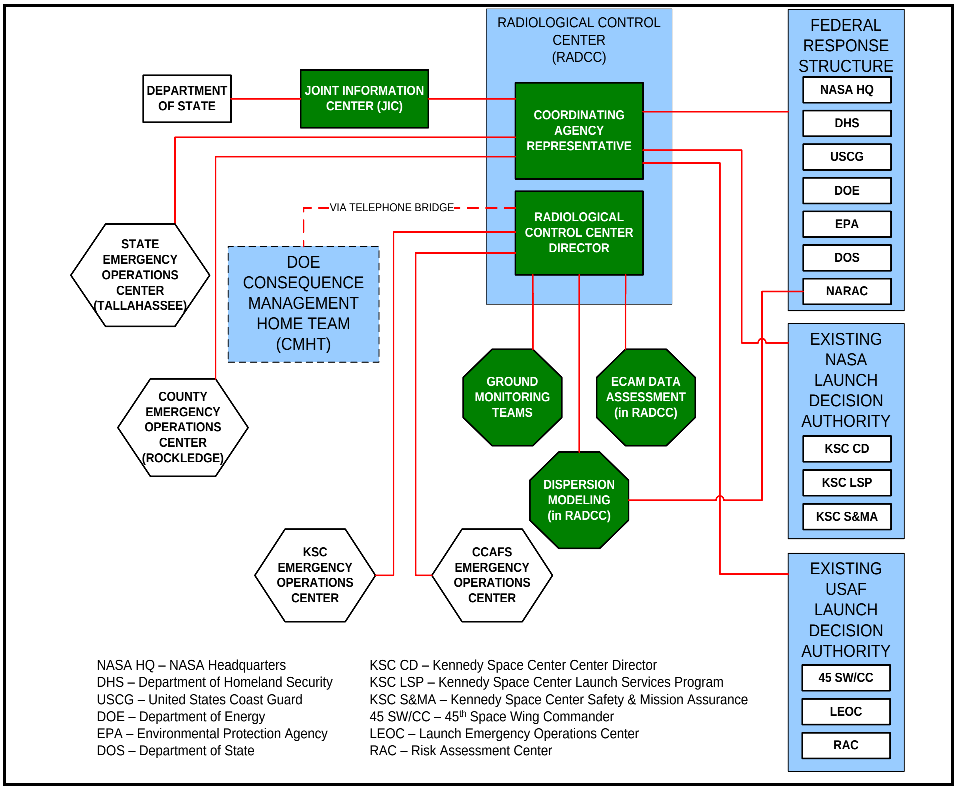

FIGURE 4. MSL RCP organizational interfaces.

NEW AUTOMATED RADIOLOGICAL MONITORING

For past missions with RTGs or Radioactive Heater Units (RHUs) (1989-2006: Galileo, Ulysses, Mars Pathfinder, Cassini, MER1, MER2, New Horizons), mobile field teams were the primarily responsible for radiological monitoring (Nickell, et al., 2011). These teams were equipped with Field Instruments for Detecting Low-Energy Radiation (FIDLERs), alpha survey meters, and high-volume air samplers (Figures 5 and 6).

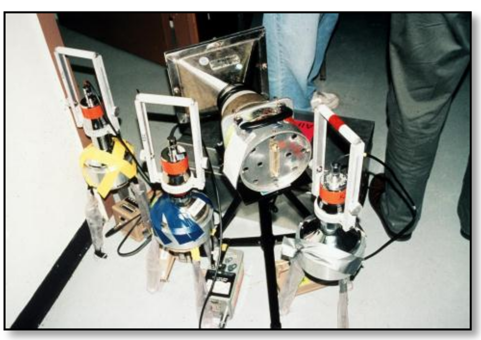

FIGURE 5. FIDLERs and high-volume air samplers.

FIGURE 6. Alpha meters.

Data collection was manual and verbally radioed to the RADCC where the data had to be recorded and processed. This pathway could take an extended period of time to complete. For the MSL launch, 16 mobile field monitoring teams consisting of health physics staff from NASA, DOE, USAF, and the FLBRC deployed to 11 locations on KSC and five sites downwind of KSC. These teams used updated DOE data tablets and Multipath Communication Devices (MPCDs) to electronically relay radiological data back to the RADCC (Figure 7). The data tablets and MPCDs reduced data transmission and processing times and greatly enhanced data accuracy.

FIGURE 7. DOE data tablet and MPCD.

To test the ability to fully automate a network of radiological measurements, NASA deployed and tested six Canberra ECAMs during the January 2006 New Horizons launch. These units provided continuous data via a direct line-of-site microwave transmission to the RADCC. For MSL, the ECAMs were upgraded to communicate via a K_A band satellite. Prior to deployment for launch support, a verification test was performed using the total complement of 30 ECAMs to demonstrate the data-collecting network could be established, maintained, and communicate data successfully. A geostationary satellite provided spot beam coverage of NASA KSC and all surrounding counties.

Figure 8 shows an ECAM and the ECAM sampling head and filter chamber. To measure alpha-emitting airborne radionuclide particulates in the respirable size range, air is first drawn into the inlets at the top of the system at breathing height. The air then passes through a cyclone chamber so that debris and large particles are forced out of the air stream as the air is drawn into the center of the instrument. The cyclone inlet limits particle sizes to an aerodynamic diameter (AD), below about 10 μm, approximately equal to the respirable size range. These respirable particles are deposited onto a 47 mm diameter filter positioned directly below the detector. Particles greater than 10 μm AD are deposited in a separate chamber for optional laboratory analysis. The alpha/beta detection system consists of a 1700 mm^2 Passivated Implanted Planar Silicon (PIPS) detector connected to a 1024-channel Digital Signal Processing (DSP) Multi-Channel Analyzer (MCA). The system includes compensated gross beta counting, enhanced alpha spectroscopy, and compensation for radon progeny that are attached to the collected particles. The energy spectrum is calibrated from approximately 0.3 MeV to 10 MeV. The region of interest (ROI) for gross beta was 0.3 MeV to 3.0 MeV; and for ^{238}Pu alpha particles was typically 5.2 MeV to 5.6 MeV. As configured, the ECAM limit of sensitivity (LOS) was equivalent to a total plume passage inhalation committed effective dose (CED) of 10 mrem. Figure 9 illustrates a deployed ECAM with the VSAT communications antenna.

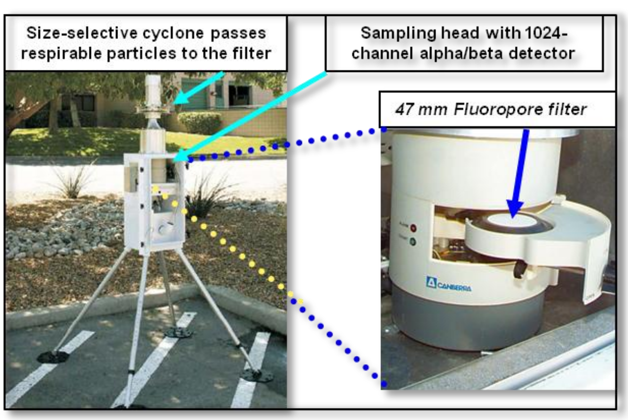

FIGURE 8. ECAM unit components.

FIGURE 9. Typical ECAM field installation with a Very Small Aperture Terminal (VSAT).

NEW WEB-BASED TOOLS

The MSL RCP included an extensive architecture developed for the exchange of data and assessment information among several geographically separated facilities. Figure 10 show how two satellites and two specialized DOE Web sites (RAMS and CMWeb) were used to link three locations – RSL, the Launch Site, and NARAC (Brisbin and Scott, 2011). The DOE NNSA space element refers to the DOE Emergency Communications Network (ECN), a satellite-based network supported by NSTec at RSL in Las Vegas, NV.

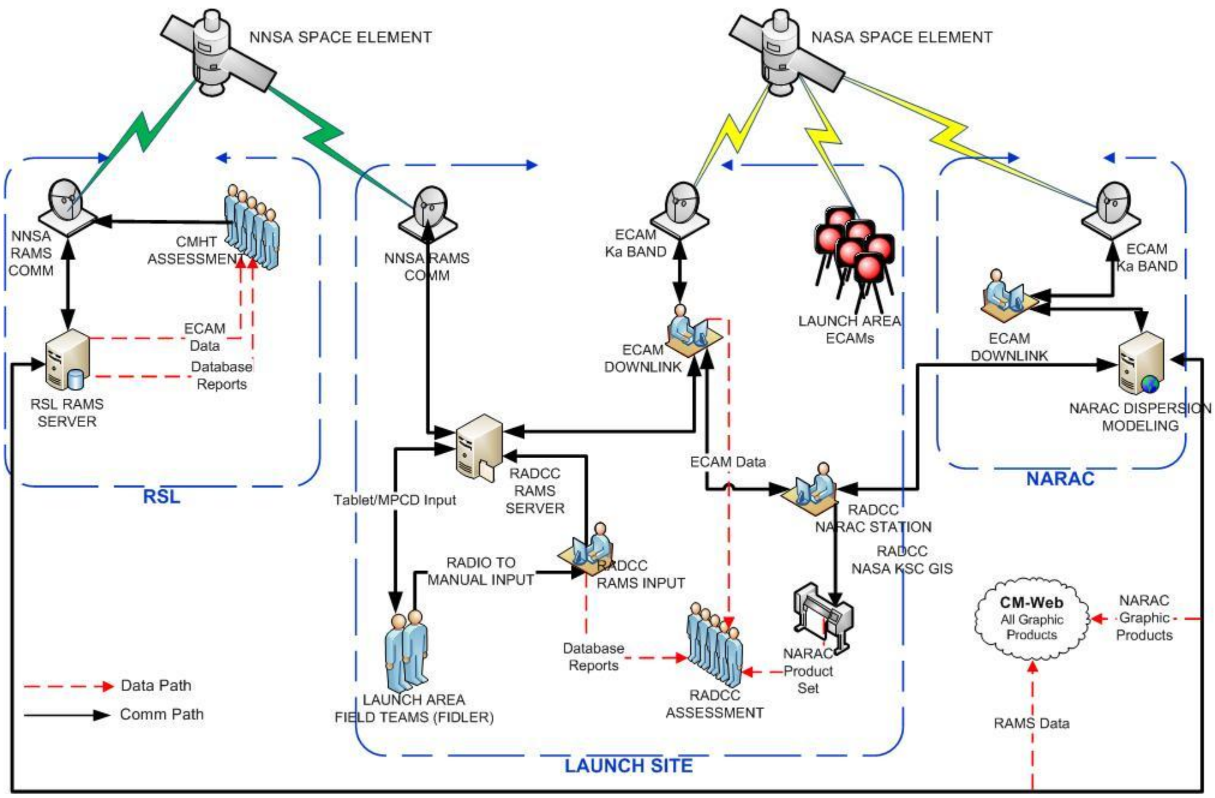

FIGURE 10. MSL RCP data and communications architecture.

Using MPCDs, field teams transmitted monitoring data directly to the Radiological Assessment and Monitoring System (RAMS) server at the RADCC. In addition to the field team data, at approximately two-minute intervals the ECAM data were automatically transferred from the VSAT to the NASA space element and then to the two ECAM Downlink Stations – a primary at the RADCC and a backup at NARAC. The LLNL-developed ECAM Data Analysis Program (eDAP) continuously validated, archived, analyzed, and displayed ECAM operational status and results in the RADCC and NARAC (Figure 11). In addition, eDAP automatically transferred selected data and results to the RAMS server for interagency access.

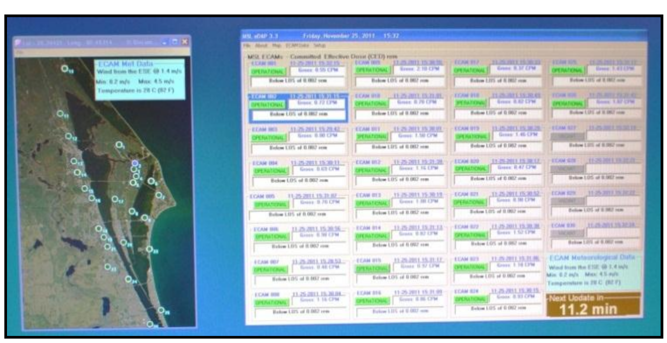

FIGURE 11. ECAM Data Analysis Program (eDAP) display.

RSL also hosts the DOE Consequence Management Home Team (CHMT), a reach-back set of experts ready to assist in analyzing measurement and modeling data and developing expert advice on managing the consequences of a radiological incident. If a significant accident were to occur, a Federal Radiological Monitoring and Assessment Center (FRMAC) team would have deployed to assist the state of Florida with potential off-site consequences.

NARAC, DOE's asset that provides dispersion modeling estimates of the consequences from airborne radiological releases (Nasstrom, et al., 2007), supported the RCP with a scientist in the RADCC as well as reach-back staff at LLNL NARAC Operations. The 41 collaborating organizations accessed NARAC and monitoring products via CMWeb, a controlled web site maintained by LLNL. The near real-time feed of ECAM radiological measurement data downwind from a release greatly enhanced NARAC's ability to adjust the model calculations to actual conditions if a launch anomaly were to occur. Also, the KSC Weather Office in collaboration with the National Weather Service Melbourne, FL Office were prepared to deliver weather radar cross-sections of the smoke plume to NARAC if an accidental fire had taken place.

PRE-LAUNCH ACTIVITIES

Prior to launch, the RADCC Technical Director assembled a small team to formulate a mission-specific implementation of the U. S. Food and Drug Administration (FDA) Derived Intervention Level (DIL). Led by the DOE Senior Science Advisor (SSA), the team developed and submitted to the FDA a "Request for Site and Incident Specific Alternate Derived Intervention Level (DIL) for Radionuclides in Food." The standard default FDA DIL for ^{238}Pu-contaminated leafy produce is 2.5 Bq/kg. The proposed site specific DIL, 43 Bq/kg, would have significantly reduced the concern for potentially contaminated food. The FDA acknowledged that the methodology for the proposed DIL was viable.

One month before the MSL launch, NASA pre-deployed 26 ECAMs (9 on KSC and 17 in the surrounding communities in Brevard County). All RADCC stations and field monitoring teams were staffed two weeks prior to the opening of the November 25 launch window. During the pre-launch period, the teams conducted extensive cross training, practiced field procedures, and conducted exercises as well as a final full launch rehearsal.

Public outreach, coordinated by the JIC Manager, was a strong component of the RCP, both through the media and directly to the public at venues such as the Brevard County Fair and a local shopping mall. One key aspect of communication to the public included the message that any radiation exposure to the public was likely to be small in comparison to common radiation exposures such as the annual natural background.

The RADCC Director, the SSA, and the MSL NASA PAO conducted several interviews and hosted a pre-launch media demonstration of RCP instrumentation and tour of the RADCC and the JIC. In addition, KSC invited Orlando-area TV weather forecasters for a background briefing and live Webinar to provide information regarding what would occur if there were an accident and how any resulting plumes or clouds might appear on their weather information resources. The briefing addressed misconceptions or questions from the weathercasters and used lessons learned from the coverage of a January 1997 Delta II launch accident (Merceret and Evans, 2000). The briefing was comprised of five following presentations:

1. The NASA MSL Mission Scientist explaining the purpose of the mission and what the Curiosity rover is expected to detect once on Mars
2. The USAF 45th Weather Squadron MSL Launch Weather Officer brief on available weather data at KSC and the expected weather conditions during launch
3. The Director of Research for KSC Weather Office illustrating how weather radar may show a smoke plume, but the fire may or may not contain radioactive particles from an MSL accident
4. The NARAC scientist explaining how NARAC uses weather forecasts as well as both onsite and offsite observations to develop detailed predictions for the potential downwind health effects from radiological accident scenarios on launch day
5. The NASA Coordinating Agency Representative for MSL Launch explaining the risks associated with the launch and the extensive interagency preparedness for such an unlikely event

A question and answer period followed the briefing. JIC representatives fielded questions about the type of messaging which would be appropriate given the state of the spacecraft and the weather conditions. Overall, the pre-launch media coverage, which contained many of the core public safety messages prepared by the JIC team, was generally fair and well-informed.

LAUNCH DAY OPERATIONS

Years of preparation, coordination, training, and exercising paid off when on November 26, 2011, the RCP team of 141 personnel supported MSL without a hitch. Following each step in the detailed launch checklist, the RCP teams met or exceeded each of the stated goals and requirements.

On launch day, NARAC provided a series of dispersion model forecasts for the downwind extent of potential releases from a set of Representative Accident Scenarios (RASs) in the launch area. NARAC derived source terms based on data from the Final Safety Analysis Report (FSAR) (Lipinski, 2010). For quality assurance throughout the launch countdown, NARAC compared its calculations with the USAF Risk Assessment Center's plots of the hydrogen chloride ground-level plume footprint from dispersion of the Atlas V's vehicle exhaust. Winds were steadily from the east throughout the day and would have carried any accidental release onshore. Three hours prior to the 10:02 a.m. EST launch, the RADCC Assessment Team directed the deployment of 4 additional mobile ECAM units (two onsite and two offsite) downwind of a potential accident plume predicted by NARAC dispersion modeling. On launch day, all 30 ECAMs were up and operational. NARAC plume predictions showed that a total of 7 ECAMs (4 fixed and 3 mobile) and up to 3 field teams would have been able to detect a radiological release if one were to occur.

The RADCC Assessment Team drew a shelter-in-place (SIP) polygon using the NARAC dose contour projections (Figure 12). Based on this map, the JIC delivered clear and specific directions to managers of the public venues in the path of the predicted release. This guidance included estimated arrival times at the venues and how long the public would need to shelter-in-place were an accident to occur.

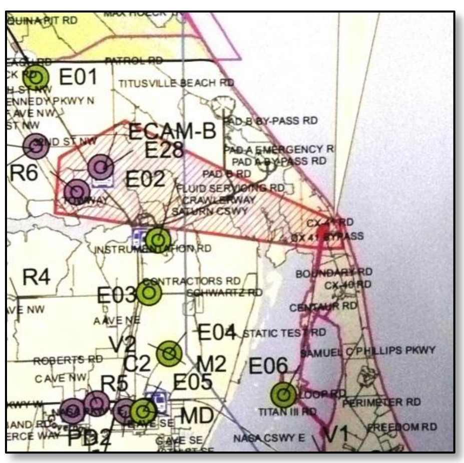

FIGURE 12. NARAC predicted SIP area for MSL launch

CONCLUSIONS

NASA, DOE, USAF, FEMA, EPA, the State of Florida, and Brevard County collaborated extensively to ensure that a robust Radiological Contingency Plan (RCP) was in place for the MSL launch of the Curiosity rover which was powered by an MMRTG. The RCP facilitated prompt, comprehensive assessments and advice to the public concerning appropriate protective actions for an unlikely accident. Considerable investment in a redesigned Radiological Control Center, a new network of automated radiological monitoring systems, and satellite links and shared Web sites greatly advanced the capability, timeliness, and coordination for the MSL RCP teams.

ACKNOWLEDGMENTS

The RCP team would like to dedicate this paper in memory of Bob Lay, who as Director of Brevard County Department of Emergency Management was enthusiastic and tireless in his efforts to insure the safety of its citizens as the radiological contingency plans were developed and carried out not only for this mission, but for several previous NASA radioisotope powered missions as well.

AUSPICES AND DISCLAIMER

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ACRONYMS

BCDEM	Brevard County Department of Emergency Management
CAR	Coordinating Agency Representative
CED	Committed Effective Dose
CMHT	Consequence Management Home Team (DOE)
CMWeb	Consequence Management Web
CMG	CAR Management Group (RADCC)
DHS	Department of Homeland Security
DIL	Derived Intervention Level (FDA)
DOE	Department of Energy
ECAM	Environmental Continuous Air Monitor
EPA	Environmental Protection Agency
FDA	Food and Drug Administration
FEMA	Federal Emergency Management Agency
FIDLER	Field Instrument for the Detection of Low Energy Radiation
FLDEM	State of Florida Department of Emergency Management
FLBRC	State of Florida Bureau of Radiation Control
FRMAC	Federal Radiological Monitoring and Assessment Center
FSAR	Final Safety Analysis Report
JPL	Jet Propulsion Laboratory
JIC	Joint Information Center
KSC	Kennedy Space Center
LLNL	Lawrence Livermore National Laboratory
LOS	Limit of Sensitivity
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator
MSL	Mars Science Laboratory
NARAC	National Atmospheric Release Advisory Center
NASA	National Aeronautics and Space Administration
NNSA	National Nuclear Security Administration (DOE)
NOAA	National Oceanic and Atmospheric Administration
NRF	National Response Framework (DHS)
NSTec	National Security Technologies, LLC
PAG	Protective Action Guide
PAR	Protective Action Recommendation
RAC	Risk Assessment Center (NASA KSC)
RAS	Representative Accident Scenario
RADCC	Radiological Control Center (NASA KSC)
RAMS	Radiological Assessment and Monitoring System
REAC/TS	Radiation Emergency Assistance Center/Training Site

RHU	Radioisotope Heater Unit
RPS	Radioisotope Power System
RSL	Remote Sensing Laboratory (NSTec)
SIP	Shelter-in-Place
SNL	Sandia National Laboratories
SSA	Senior Science Advisor
USG	U.S. government
USAF	United States Air Force
VSAT	Very Small Aperture Terminal (Ka-Band)

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